Passive Acoustic Methods for Tracking Marine Mammals Using Widely-Spaced Bottom-Mounted Hydrophones

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LONG-TERM GOALS

The long-term goal of this project is to improve passive acoustic methods for tracking marine mammals, with primary effort dedicated to methods that use bottom-mounted hydrophones. When possible, tracking results are used to study marine mammal behavior and bioacoustics.

OBJECTIVES

The main objective of this project is to develop and implement methods to deal with two specific challenges associated with tracking marine mammals using widely-spaced bottom-mounted hydrophone arrays: (1) Multiple animals whose calls cannot be easily separated or associated, and (2) Insufficient receiver coverage, in which case standard time-of-arrival (TOA) tracking methods fail.

APPROACH

This project uses existing datasets to develop and apply the tracking methods. The main effort is directed toward data collected at Navy Ranges (esp. AUTEC and PMRF), but other datasets that use bottom-mounted sensors are also be considered if they are available and appropriate. The main species of interest are sperm whales, beaked whales, minke whales, and humpback whales. Most methods will be generalizable to other species.

Although the two main tracking challenges addressed by this project (insufficient receiver coverage and multiple animals) are not exclusive of one another, initial efforts focus on isolating the problems (by identifying periods in a datasets with only one problem, for example) and solving them separately. As the separate challenges are met, efforts will progress to the joint problem.

Model-based tracking methods [Thode 2005; Tiemann et al. 2004; Nosal 2007] are used since they can account for depth-dependent sound speed profiles (particularly important as refraction becomes significant at long distances, such as on Navy ranges [Chapman 2004]) and since they can accurately model and make use of multi-path arrivals. Methods are implemented using a Bayesian framework to incorporate available a priori information (e.g. maximum possible swim speed), get error estimates on position, and improve performance in uncertain and fluctuating environments. In this framework, a three dimensional grid is created and the likelihood of an animal present is calculated for each grid

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15. SUBJECT TERMS

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point and time. Calculations are based on measured TOAs, modeled TOAs, estimated uncertainties, and any available a priori information. All methods are fully automated through MATLAB code.

Eva-Marie Nosal is the key individual participating in this work as the principal investigator and main researcher.

WORK COMPLETED

The first version of a tracing tool that connects related elements in a space has been implemented [Nosal 2008] (the word "tracing" is used instead of "tracking" to avoid confusion with the 3D tracking problem). This version uses a flood-fill algorithm (commonly used in paint programs as the "bucket tool") to connect neighboring and related elements in an array. The tracing tool is useful in various parts of this research, such as in extracting call contours from spectrograms (Fig. 1), filling in lossy time-difference of arrival tracks, and constructing 3D animal tracks from snapshot position estimates.

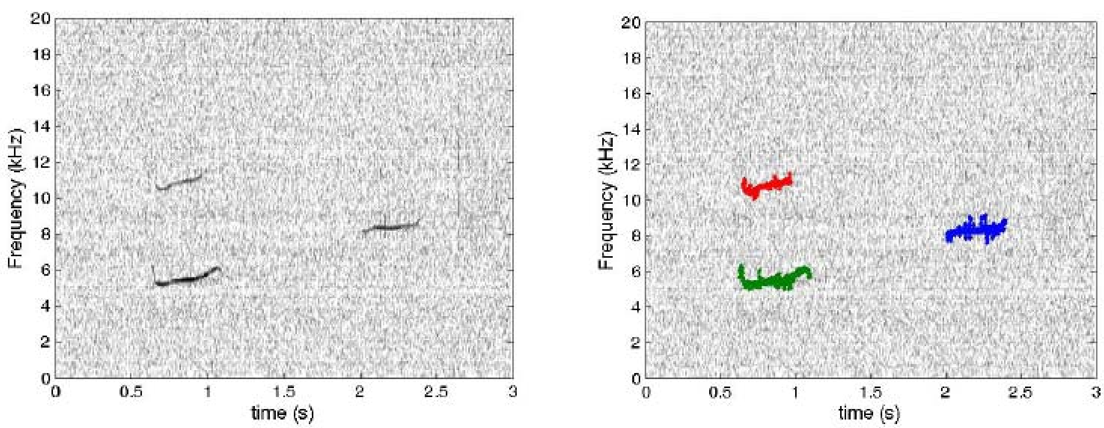

Figure 1. Signal detection via flood-fill tracing tool applied to spectrograms. Left: De-noised spectrogram before flood-fill. Right: Detections resulting from applying the flood-fill detector.

The tracing tool was tested by applying it to spectrograms in a detection task [Nosal 2008] for data collected by a HARP [Wiggins 2007] at about 400m depth on the summit of Cross Seamount, approximately 290 km south of the Hawaiian island of Oahu (dataset provided by Jeff Polovina and Dave Johnston of the Pacific Islands Fisheries Science

Center, U.S. National Marine Fisheries Service, Hawaii). Detections were post-processed by grouping via an automated procedure according to frequency characteristics, duration, and contours. Manual inspection of the detections in each group classified them as: system noise, echosounder, ship tonals, low frequency clicks (sperm whales), high frequency clicks (dolphins, pilot whales…), whistles, and frequency modulated clicks (beaked whales).

The track of a single sperm whale in a multiple-animal dataset recorded at the AUTEC range was established by applying the tracing tool to source position likelihood volumes calculated using a model-based time of arrival method [Nosal 2008]. The tracing method is useful since maxima in the likelihood volume for a single time step does not necessarily signify the presence of a true source; spurious sources are common due noise, incorrectly associated vocalizations and so on. However, since a vocalizing animal moves relatively slowly in space and time, a connected path of maxima

(established via the tracing tool) gives confidence in position estimates and provides an estimated source track.

A method that relies on slowly varying time of arrival differences (TDOAs) was developed to associate calls from multiple animals over different hydrophones. A scatterplot of TDOAs vs TOAs (Fig. 2) shows persistent lines that correspond to correctly associated clicks from a single animal. Incorrectly associated clicks add noise (scatter). This technique was applied to a multiple sperm whale dataset from AUTEC to track 4 animals simultaneously. Results were presented at the Acoustical Society of America Meeting in Portland, May 2009. Ongoing efforts aim to automate the process of

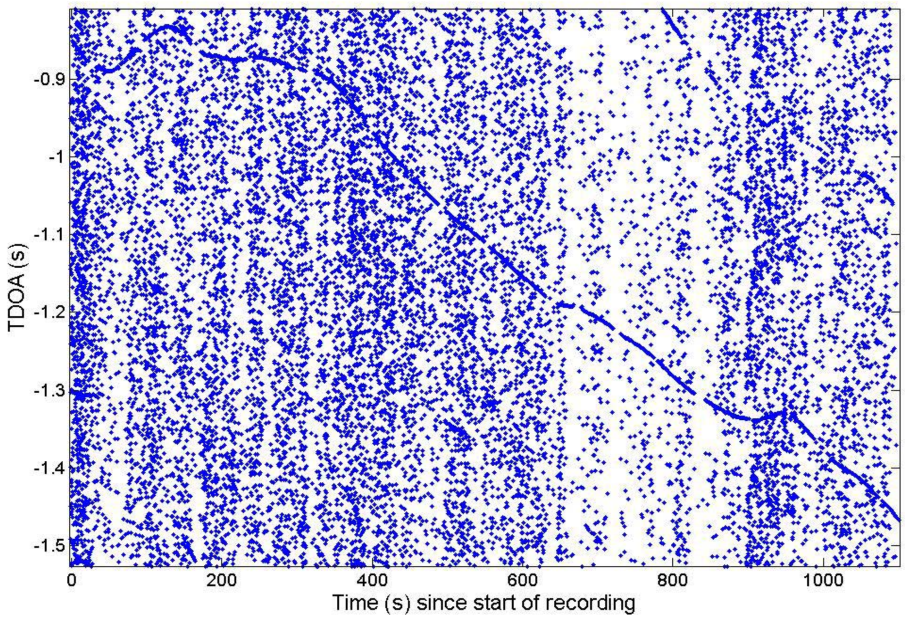

Figure 2. Zoom in on a scatterplot of TDOA vs TOA for a multiple sperm whale dataset. A persistent line corresponds to a single animal while noise comes from incorrectly associated clicks.

The model-based TDOA methods were tested on tracking dataset of the 4th International Workshop on Detection, Classification and Localization of Marine Mammals Using Passive Acoustics (Sept. 2009, Pavia, Italy). Hydrophones were bottom-mounted and closely spaced (~1m) in a tetrahedral configuration. Using direct arrivals only, bearing and elevation could be estimated to within a few degrees.

RESULTS

A detector that traces contours in spectrograms can automatically detect unknown and unexpected transients in large and unexplored datasets. Although it is not optimal for expected or known sounds (where matched filters or other tuned detectors perform much better), it can be useful as a "first sweep" for large volumes of data in which unknown or unpredictable sounds might be present. With further development, the type of general and automated transient detector could be useful for relieving some of the demands on time-consuming manual inspection of acoustic data.

Scatterplots of TDOAs vs. TOA can be useful for separating and associating calls between hydrophones in the case of multiple calling animals. Associating calls is a critical step for tracking work, and will also benefit efforts aimed at counting animals (without necessarily tracking them).

Methods developed for widely-spaced hydrophones can be useful for processing data from compact arrays to obtain bearing and elevation estimates for vocalizing animals. Range can be obtained by using two compact arrays and/or reflections. Tetrahedral configurations can be more useful than line arrays in high signal-to-noise situations since they give both bearing and elevation. The benefits of compact arrays over widely-spaced arrays include: cost-effectiveness, ease of deployment & recovery, fewer time-synchronization problems, fewer problems associated with beam directivity, easier click association. Drawbacks include: smaller area coverage, unknown animal range (if reflections are not present and only one array is used), potentially large position uncertainties.

IMPACT/APPLICATIONS

The the localization and tracking methods developed in this project will be useful for monitoring and studying marine mammal bioacoustics and behavior in the wild. Tracking results can be used to establish detection ranges and calling rates that are critical in density estimation applications. Methods developed to track marine mammals are useful for sources other than marine mammals (e.g. tracking of surface vessels can help to monitor fishing efforts in marine protected areas).

RELATED PROJECTS

Model-based tracking methods developed in this project are used to support ONR award N000140910489: The ecology and acoustic behavior of minke whales in the Hawaiian and Pacific Islands. Acoustic data collected at PMRF by Steve Martin are post-processed

to verify the 2D minke whale tracks obtained by Mr. Martin. Acoustically derived positions are compared with concurrent visual sightings by a team led by Tom Norris aboard the R/V Dariabar.

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PUBLICATIONS

Nosal E-M (2008). Flood-fill algorithms used for passive acoustic detection and tracking. Proceedings of the IEEE Workshop & Exhibition on New Trends for Environmental Monitoring using Passive Systems, Hyeres, France, ISBN: 978-1-4244-2816-8, IEEE Catalog Number: CFP08PSY-CDR [non-refereed, published].